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Ding et al.

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(54) **SYSTEM AND METHOD FOR CLASSIFICATION OF THREE-DIMENSIONAL MODELS IN A VIRTUAL ENVIRONMENT**

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G09B 25/04 (2006.01)

(52) **U.S. Cl.**
CPC ***G06T 17/05*** (2013.01); ***G09B 25/04*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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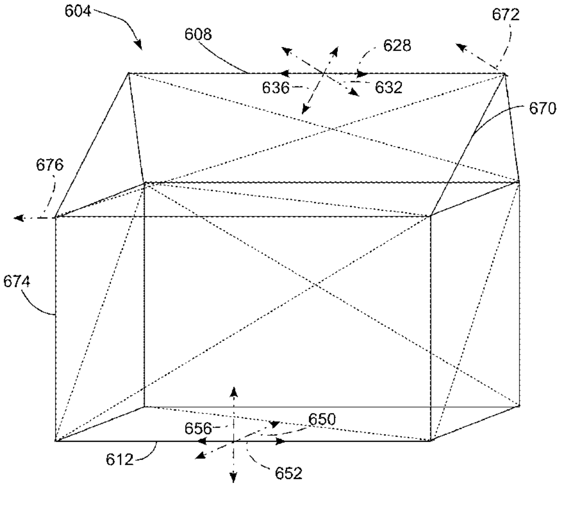
(57) **ABSTRACT**

A method for classification of three-dimensional structures in a virtual environment includes identifying a plurality of polygons in a structure located in a virtual environment, identifying a plurality of surface normals, each surface normal corresponding to one polygon in the plurality of polygons that are in the structure, identifying a variance of a distribution of the plurality of surface normals, generating a first classification for the structure in response to the variance being less than a predetermined threshold, and generating a graphical display of the structure with at least one visual aspect of the structure being modified with reference to the first classification.

28 Claims, 8 Drawing Sheets



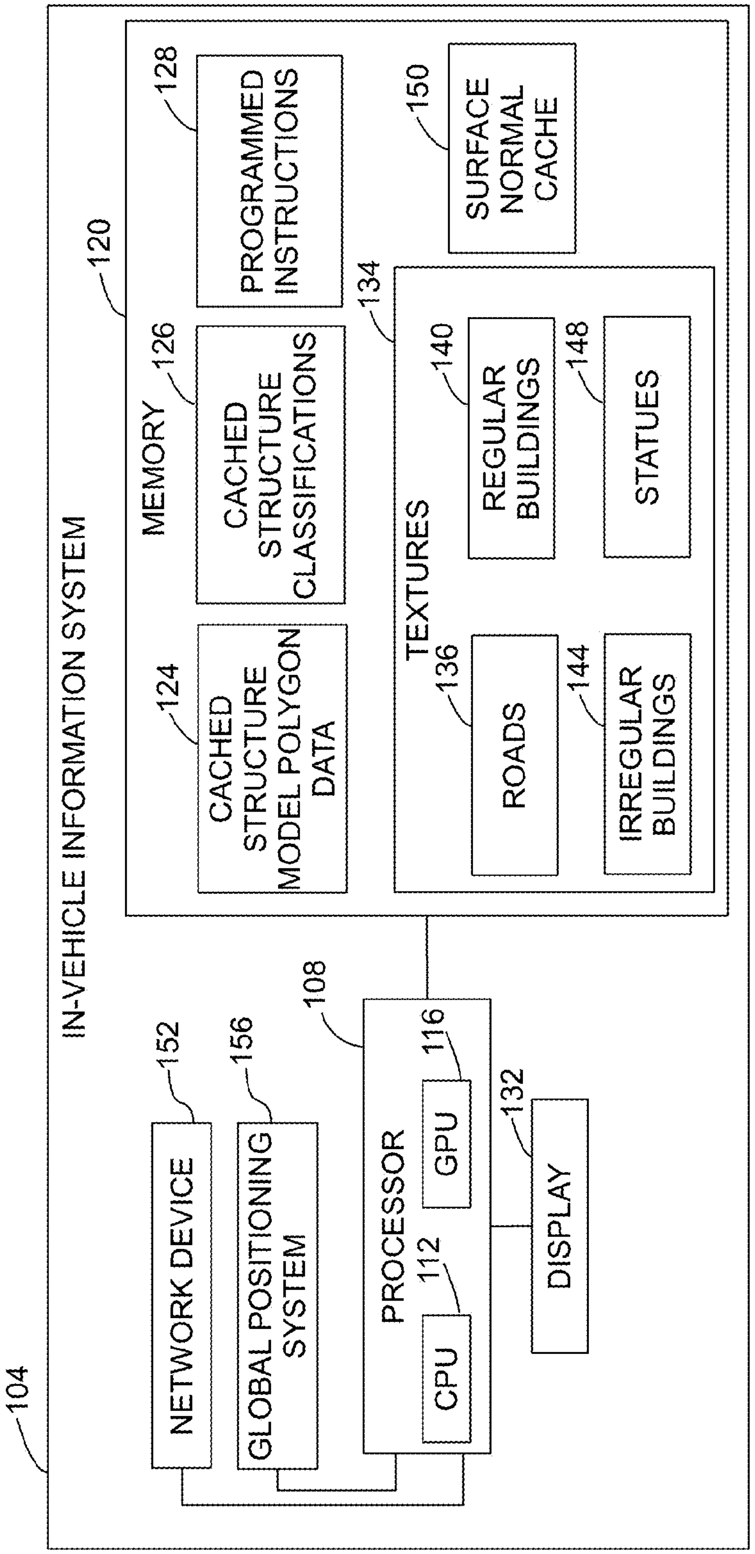

104
IN-VEHICLE INFORMATION SYSTEM
152
NETWORK DEVICE
156
GLOBAL POSITIONING SYSTEM
108
PROCESSOR
112
CPU
116
GPU
132
DISPLAY
120
MEMORY
124
CACHED STRUCTURE MODEL POLYGON DATA
126
CACHED STRUCTURE CLASSIFICATIONS
128
PROGRAMMED INSTRUCTIONS
134
TEXTURES
136
ROADS
140
REGULAR BUILDINGS
144
IRREGULAR BUILDINGS
148
STATUES
150
SURFACE NORMAL CACHE

FIG. 1

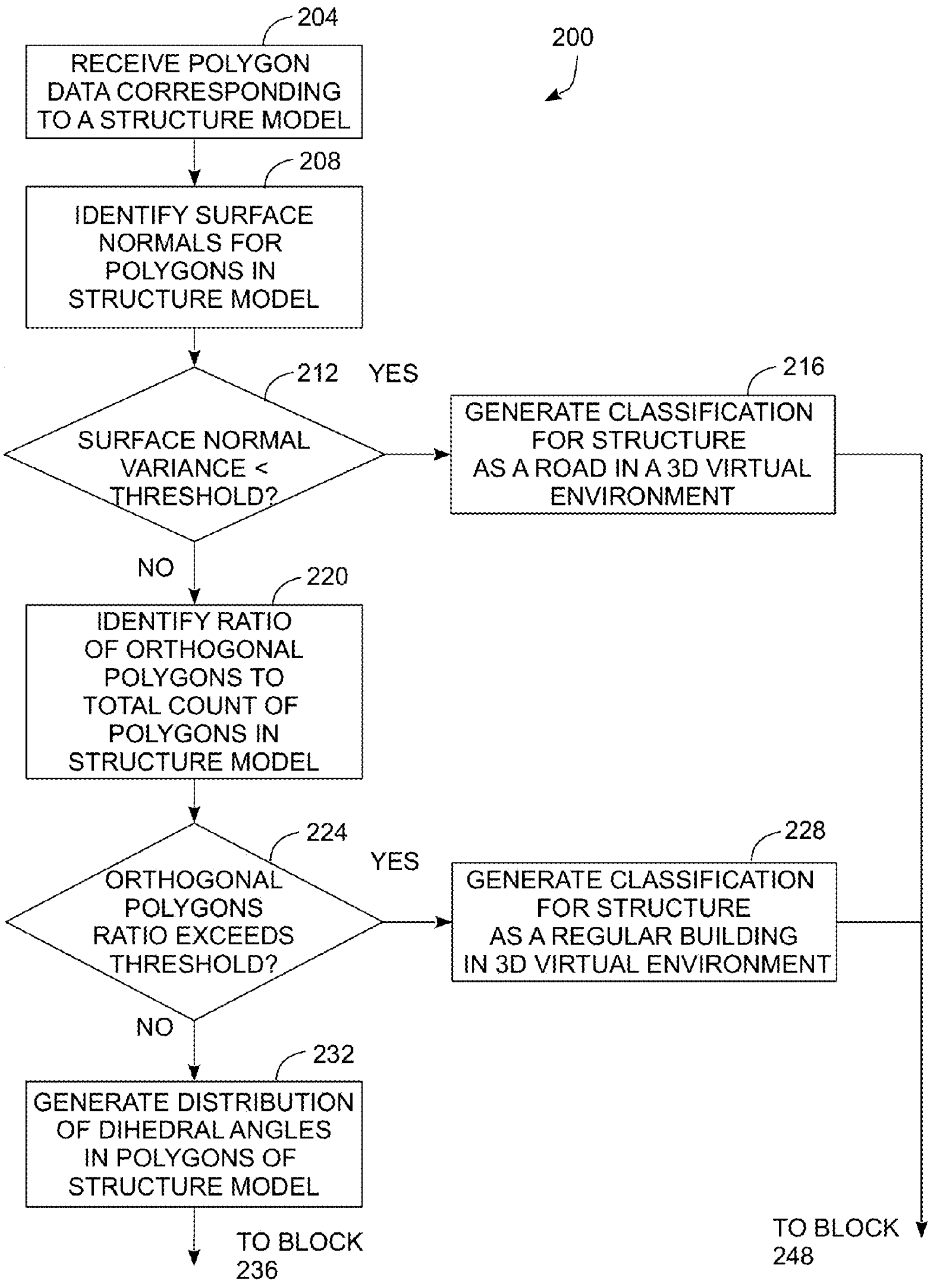

200
204
RECEIVE POLYGON DATA CORRESPONDING TO A STRUCTURE MODEL
208
IDENTIFY SURFACE NORMALS FOR POLYGONS IN STRUCTURE MODEL
212
SURFACE NORMAL VARIANCE < THRESHOLD?
YES
216
GENERATE CLASSIFICATION FOR STRUCTURE AS A ROAD IN A 3D VIRTUAL ENVIRONMENT
NO
220
IDENTIFY RATIO OF ORTHOGONAL POLYGONS TO TOTAL COUNT OF POLYGONS IN STRUCTURE MODEL
224
ORTHOGONAL POLYGONS RATIO EXCEEDS THRESHOLD?
YES
228
GENERATE CLASSIFICATION FOR STRUCTURE AS A REGULAR BUILDING IN 3D VIRTUAL ENVIRONMENT
NO
232
GENERATE DISTRIBUTION OF DIHEDRAL ANGLES IN POLYGONS OF STRUCTURE MODEL
TO BLOCK 236
TO BLOCK 248

FIG. 2

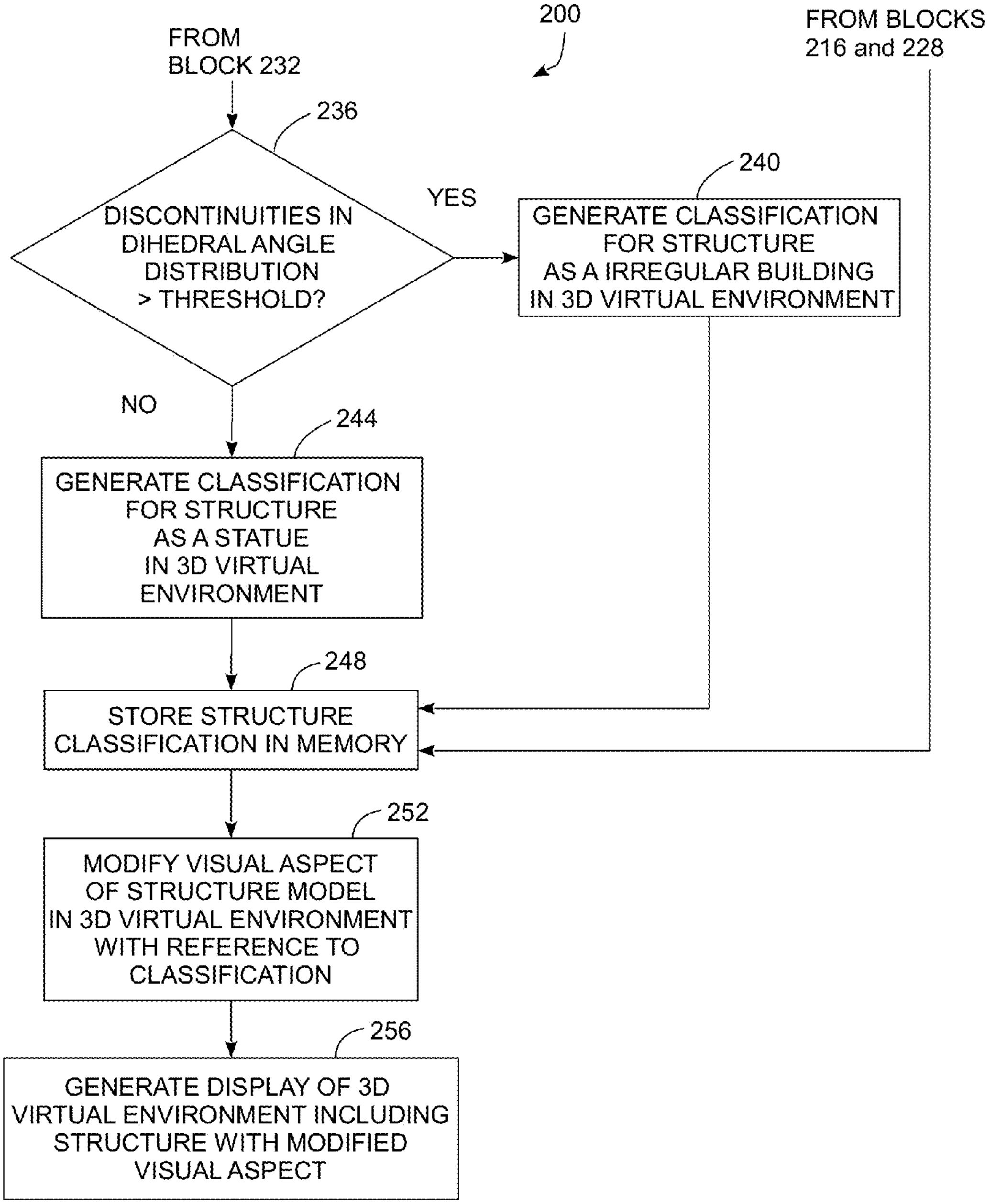

200
FROM BLOCK 232
236
DISCONTINUITIES IN DIHEDRAL ANGLE DISTRIBUTION > THRESHOLD?
YES
NO
240
GENERATE CLASSIFICATION FOR STRUCTURE AS A IRREGULAR BUILDING IN 3D VIRTUAL ENVIRONMENT
FROM BLOCKS 216 and 228
244
GENERATE CLASSIFICATION FOR STRUCTURE AS A STATUE IN 3D VIRTUAL ENVIRONMENT
248
STORE STRUCTURE CLASSIFICATION IN MEMORY
252
MODIFY VISUAL ASPECT OF STRUCTURE MODEL IN 3D VIRTUAL ENVIRONMENT WITH REFERENCE TO CLASSIFICATION
256
GENERATE DISPLAY OF 3D VIRTUAL ENVIRONMENT INCLUDING STRUCTURE WITH MODIFIED VISUAL ASPECT

FIG. 2
(CONTINUED)

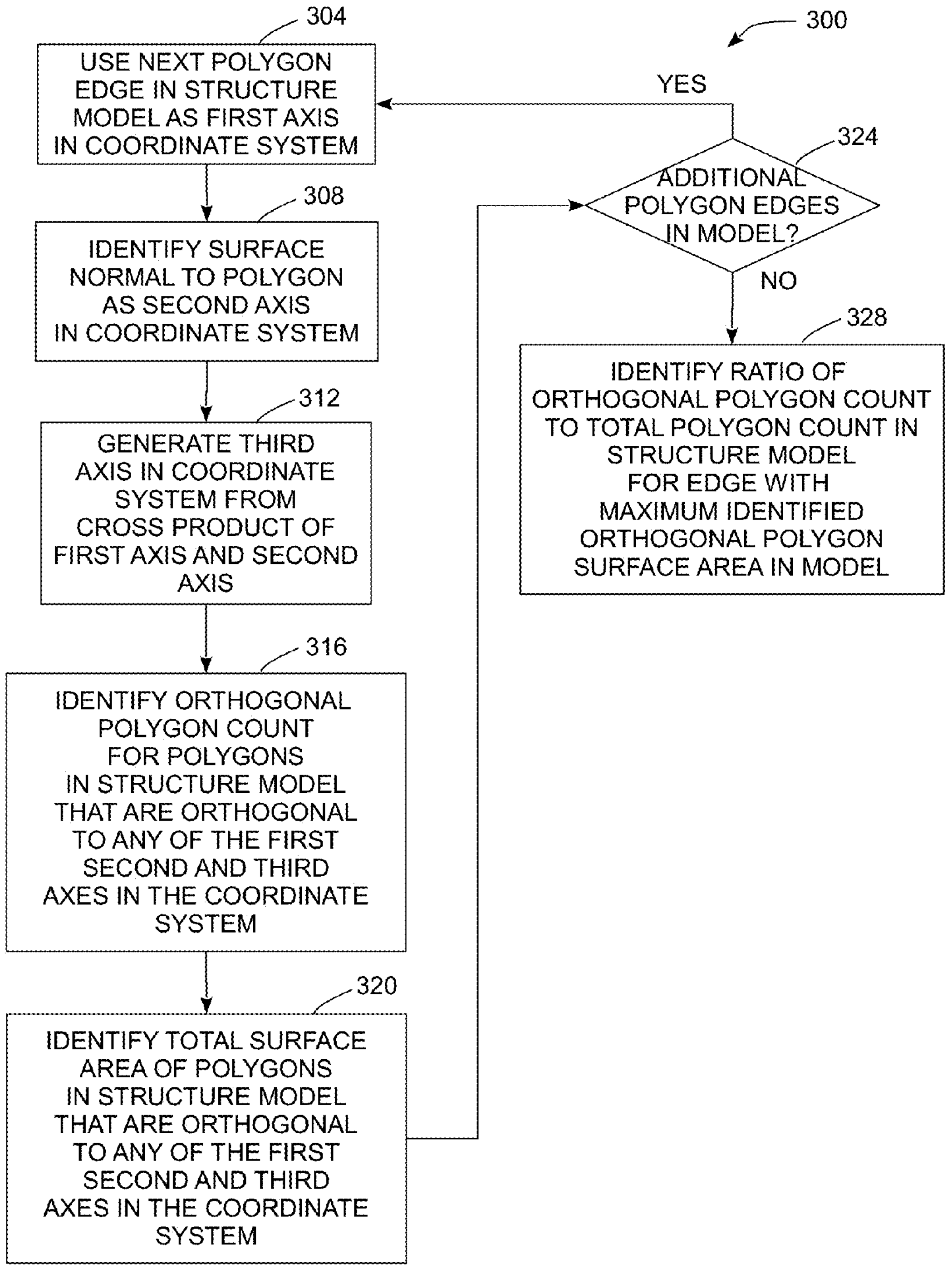

300
304
USE NEXT POLYGON EDGE IN STRUCTURE MODEL AS FIRST AXIS IN COORDINATE SYSTEM
308
IDENTIFY SURFACE NORMAL TO POLYGON AS SECOND AXIS IN COORDINATE SYSTEM
312
GENERATE THIRD AXIS IN COORDINATE SYSTEM FROM CROSS PRODUCT OF FIRST AXIS AND SECOND AXIS
316
IDENTIFY ORTHOGONAL POLYGON COUNT FOR POLYGONS IN STRUCTURE MODEL THAT ARE ORTHOGONAL TO ANY OF THE FIRST SECOND AND THIRD AXES IN THE COORDINATE SYSTEM
320
IDENTIFY TOTAL SURFACE AREA OF POLYGONS IN STRUCTURE MODEL THAT ARE ORTHOGONAL TO ANY OF THE FIRST SECOND AND THIRD AXES IN THE COORDINATE SYSTEM
324
ADDITIONAL POLYGON EDGES IN MODEL?
YES
NO
328
IDENTIFY RATIO OF ORTHOGONAL POLYGON COUNT TO TOTAL POLYGON COUNT IN STRUCTURE MODEL FOR EDGE WITH MAXIMUM IDENTIFIED ORTHOGONAL POLYGON SURFACE AREA IN MODEL

FIG. 3

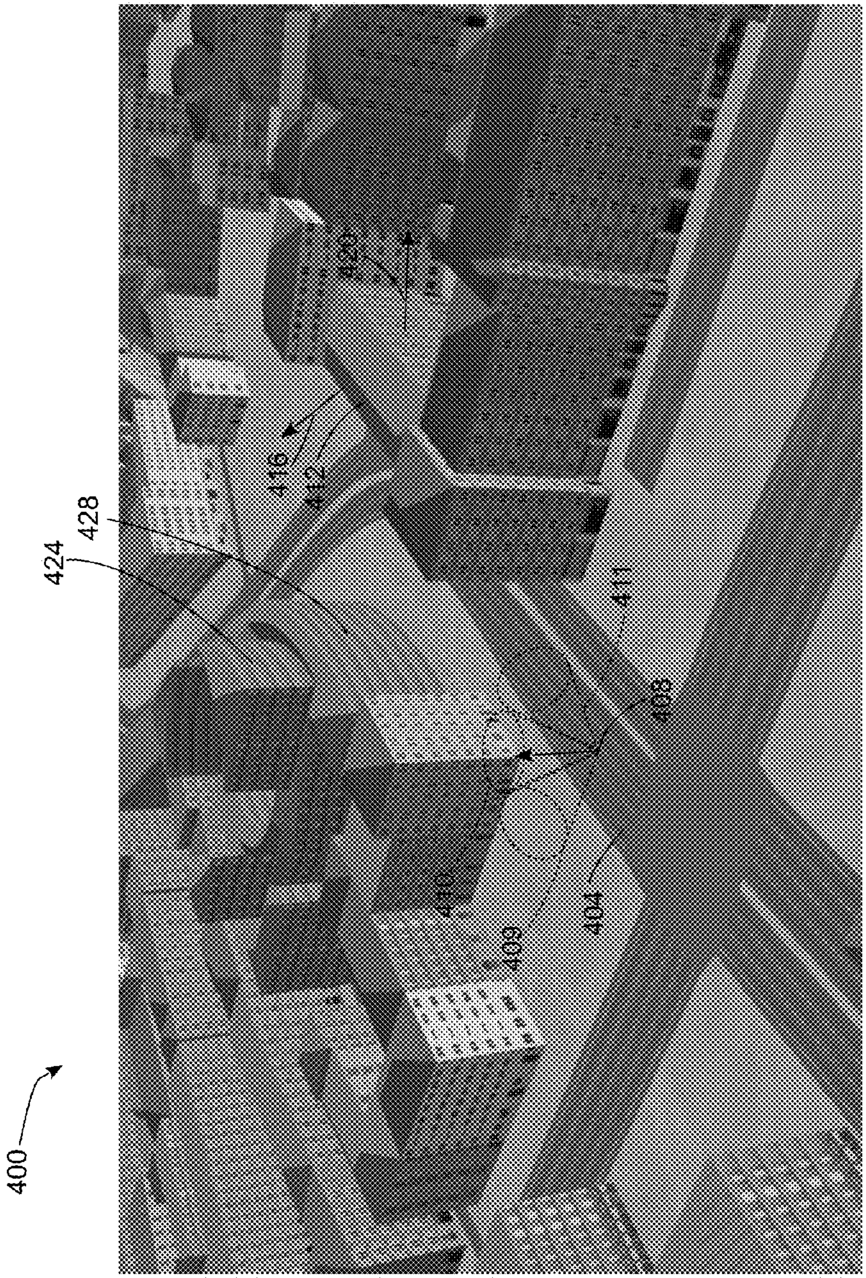


FIG. 4

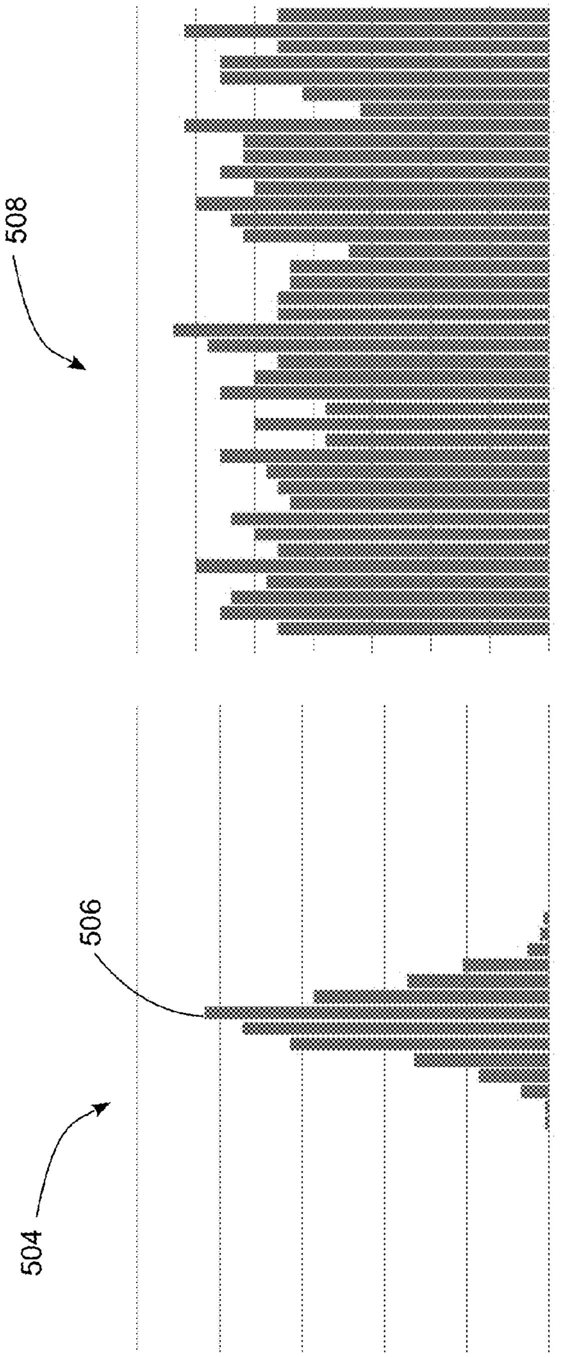


FIG. 5

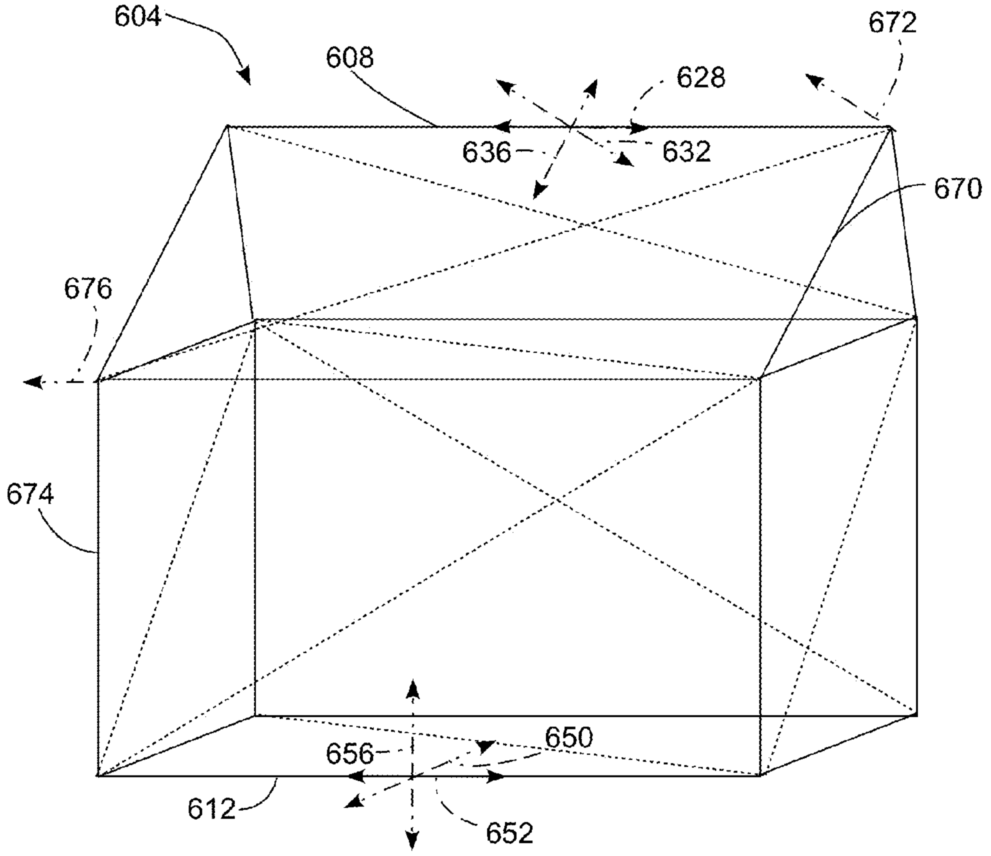
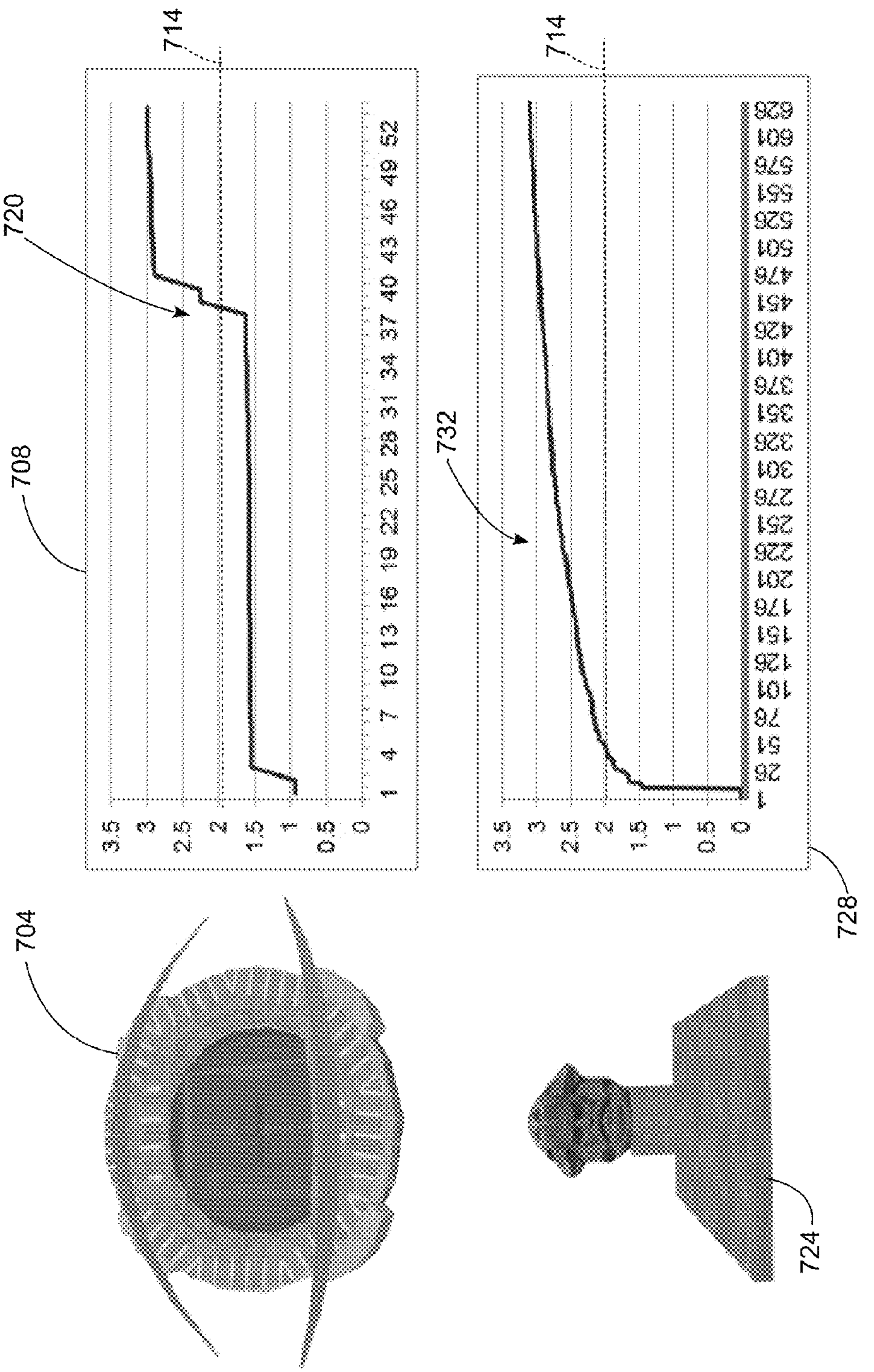


FIG. 6



704
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714
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1 26 51 78 101 126 151 176 201 226 251 276 301 326 351 376 401 426 451 476 501 526 551 576 601 628
724
728

FIG. 7

SYSTEM AND METHOD FOR CLASSIFICATION OF THREE-DIMENSIONAL MODELS IN A VIRTUAL ENVIRONMENT

FIELD

This disclosure relates generally to the field of computer graphics and, more specifically, to systems and methods that display three-dimensional graphics.

BACKGROUND

Many modern software applications display three-dimensional representations of structures and scenes as part of a user interface. Three-dimensional (3D) graphics are used in a wide range of applications including video games, simulations, virtual reality applications, geospatial information applications, and applications for mapping and navigation. In many applications, 3D graphics are more useful than two-dimensional (2D) graphics at depicting real-world environments and locations because the normal interaction between humans and the real-world occurs in three dimensions.

In one form of 3D graphics, different objects in a scene are formed from a large number of polygons. The polygons form shapes and structures in a 3D scene. Since most computing devices only display graphics with a two-dimensional display, the 3D graphics are converted into a rasterized array of two-dimensional pixels for display. The 2D display depicts portions of the three-dimensional scene in a manner similar to how a camera takes a two-dimensional photograph of 3D scenes in the real world. Many 3D graphics systems and application programming interfaces (APIs), which include the Open Graphics Library (OpenGL) and the Direct 3D APIs, provide common structures and interfaces to specialized graphics hardware for generation of 3D images in an efficient manner. The 3D software interacts with general purpose and specialized digital computing hardware that generates the 3D graphics in an efficient manner. In particular, graphical processing units (GPUs) are hardware components that are configured to generate polygons and other graphical effects that form a 3D scene. Modern computing devices typically execute software with a combination of instructions for a central processing unit (CPU) and a GPU to generate the 3D scene and enable interaction with the 3D scene in some software applications. In some hardware embodiments, the functionality of the CPU and GPU are merged together, physically and optionally logically, into a single system on a chip (SoC) device.

Some 3D software applications are used to model virtual environments that correspond to real-world environments. For example, mapping and navigation applications produce 3D graphical depictions of a geographic region to assist a user in finding a point of interest or navigating to a destination. The 3D environment includes a large number of objects that represent real-world structures, including natural landmarks, roads, buildings, and other man-made structures. In addition to displaying the 3D objects in the virtual environment, the mapping and navigation applications often provide additional information about the objects in the environment. For example, mapping and navigation applications often highlight roads and display road names or numbers to assist in navigation. Mapping programs often display names and links to websites for points of interest around the map. Many devices that display 3D virtual environments are also connected to external databases through data networks, such as wireless data networks. The external databases store 3D models that depict roads, buildings, and other structures in a geographic region.

While 3D models that are loaded from external databases can be displayed in the virtual environment, the 3D objects often lack classification information to identify what the 3D model represents. For example, a 3D object that depicts a section of a highway does not include information that distinguishes the highway from another 3D object that depicts an office building. In order to display the 3D objects in an accurate context, a mapping or navigation program needs to classify the 3D objects in the virtual environment. Consequently, improvements to systems and methods for classifying and displaying 3D objects in a virtual environment would be beneficial.

SUMMARY

In one embodiment, a method for classifying and displaying a structure in a virtual environment has been developed. The method includes identifying a plurality of polygons in a structure located in a virtual environment, generating data corresponding to a plurality of surface normals, each surface normal corresponding to one polygon in the plurality of polygons in the structure, identifying a variance of a distribution of the plurality of surface normals, generating a first classification for the object in response to the identified variance being below a first predetermined threshold, and generating with a display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the first classification.

In another embodiment, a system that classifies and displays a structure in a virtual environment has been developed. The system includes a memory configured to store data corresponding to a plurality of polygons in a structure in a virtual environment and data corresponding to a plurality of textures for structures in the virtual environment. The system also includes a display device configured to generate a display of the structure in the virtual environment and a processor operatively connected to the memory and the display. The processor is configured to generate data corresponding to a plurality of surface normals for the data corresponding to the plurality of polygons in the structure, each surface normal corresponding to one polygon in the plurality of polygons in the structure, identify a variance of a distribution of the plurality of surface normals, generate a first classification for the object in response to the identified variance being below a first predetermined threshold, and generate with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the first classification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a navigation system including an in-vehicle information system that is configured to display structures in a 3D virtual environment.

FIG. **2** is a block diagram of a process for classification and display of structures in a 3D virtual environment.

FIG. **3** is a block diagram of a process for identification of a ratio of orthogonal polygons to a total number of polygons in polygon data for a structure model.

FIG. **4** is a depiction of a scene in a 3D virtual environment including structures in the virtual environment.

FIG. **5** is a depiction of a distribution of surface normals in polygon data for a road structure in a 3D virtual environment and a depiction of another distribution of surface normals for a non-road structure in the 3D virtual environment.

FIG. **6** is a view of polygons that form a regular building structure in a 3D virtual environment.

FIG. **7** is a first depiction of an irregular building structure model in a 3D virtual environment and a corresponding sorted distribution of dihedral angles between polygons in the irregular building structure model and another depiction a statue structure model with a corresponding sorted distribution of dihedral angles between polygons in the statue structure model.

DETAILED DESCRIPTION

For the purposes of promoting an understanding of the principles of the embodiments disclosed herein, reference is now made to the drawings and descriptions in the following written specification. No limitation to the scope of the subject matter is intended by the references. The present disclosure also includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the disclosed embodiments as would normally occur to one skilled in the art to which this disclosure pertains.

As used herein, the term "in-vehicle information system" refers to a computerized system that is associated with a vehicle for the delivery of information to an operator and other occupants of the vehicle. In motor vehicles, the in-vehicle information system is often physically integrated with the vehicle and is configured to receive data from various sensors and control systems in the vehicle. In particular, some in-vehicle information systems receive data from navigation systems including satellite-based global positioning systems and other positioning systems such as cell-tower positioning systems and inertial navigation systems. Some in-vehicle information system embodiments also include integrated network devices, such as wireless local area network (LAN) and wide-area network (WAN) devices, which enable the in-vehicle information system to send and receive data using data networks. In an alternative embodiment, a mobile electronic device provides some or all of the functionality of an in-vehicle information system. Examples of mobile electronic devices include smartphones, tablets, notebook computers, handheld GPS navigation devices, and any portable electronic computing device that is configured to perform mapping and navigation functions. The mobile electronic device optionally integrates with an existing in-vehicle information system in a vehicle, or acts as an in-vehicle information system in vehicles that lack built-in navigation capabilities including older motor vehicles, motorcycles, aircraft, watercraft, and many other vehicles including, but not limited to, bicycles and other non-motorized vehicles.

As used herein, the term "object" refers to data that correspond to a group of polygons in a virtual environment that form a model of a single object in the larger virtual environment. As used herein, the term "structure" refers to an object with polygons that are positioned and oriented in the 3D virtual environment to stand on a virtual representation of ground or the surface of the earth. Common examples of structures include representations of manmade objects such as buildings, bridges, monuments, and other artificial constructions.

As used herein, the term "surface normal" refers to a vector that extends from the surface of a polygon in a perpendicular direction to the plane of the polygon in a three-dimensional space. One technique that is known to the art for generation of a surface normal vector is to perform a cross-multiplication of two vectors that correspond to two non-parallel sides of the polygon.

FIG. **1** depicts an in-vehicle information system **104** that is configured to generate a display of a 3D virtual environment. The in-vehicle information system **104** includes a processor **108**, a memory **120**, display device **132**, network device **152**, and a global positioning system device **156**. The memory **120** stores cached polygon data **124** corresponding to one or more structures that are displayed in a 3D virtual environment, cached classification identifiers **126** corresponding to the structures, programmed instruction data **128**, texture memory **134**, and an optional cache of surface normal data **150**, which includes vector data of surface normals for the polygons in the structure data **124**.

In the in-vehicle information system **104**, the processor **108** includes one or more integrated circuits that implement the functionality of a central processing unit (CPU) **112** and graphics processing unit (GPU) **116**. In some embodiments, the processor is a system on a chip (SoC) that integrates the functionality of the CPU **112** and GPU **116**, and optionally other components including the memory **120**, network device **152**, and global positioning system **156**, into a single integrated device. In one embodiment, the CPU is a commercially available central processing device that implements an instruction set such as one of the x86, ARM, Power, or MIPs instruction set families. The GPU includes hardware and software for display of both 2D and 3D graphics. In one embodiment, processor **108** includes software drivers and hardware functionality in the GPU **116** to generate 3D graphics using the OpenGL, OpenGL ES, or Direct3D graphics application programming interfaces (APIs). For example, the GPU **116** includes one or more hardware units including geometry processing units, vertex shader units, fragment shader units, and image rasterization units for the generation of a rasterized 2D depiction of a 3D virtual environment. During operation, the CPU **112** and GPU **116** execute stored programmed instructions **128** that are retrieved from the memory **120**. In one embodiment, the stored programmed instructions **128** include operating system software and one or more software application programs, including a mapping and navigation application program. The processor **108** executes the mapping and navigation program and generates 2D and 3D graphical output corresponding to maps and map features through the display device **132**.

The memory **120** includes both non-volatile memory and volatile memory. The non-volatile memory includes solid-state memories such as NAND flash memory, magnetic and optical storage media, or any other suitable data storage device that retains data when the in-vehicle information system **104** is deactivated or loses electrical power. The volatile memory includes static and dynamic random access memory (RAM) that stores software and data, including graphics data and map feature data, during operation of the in-vehicle information system **104**.

In in-vehicle information system **104**, the memory **120** stores the cache of structure data **124**. The data for each structure includes a plurality of vertex coordinates for polygons that form the structure. In some embodiments, the processor **108** retrieves structure data from one or more online data storage systems using the network device **152**. As described below, the processor **108** is configured to identify a classification for one or more structures in the memory **120**, and the cached structure classifications store generated classification data for each structure in association with the structure data **124**. The processor **108** performs the classification process once for each structure and subsequently generates a graphical depiction of the structure with selected textures from the texture memory **134**. In the embodiment of FIG. **1**, the texture memory stores one or more textures that correspond to roads **136**, regular buildings **140**, irregular buildings **144**, and statues **148**. The textures stored in the memory **134** provide more uniform appearances to a wide range of structures that are displayed in the virtual environment to provide a simplified depiction of the virtual environment to occupants in the vehicle.

In the embodiment of FIG. **1**, the processor **108** sends and receives data using the network device **152**. In a vehicle, the network device **152** is often a wireless network device, such as a wireless wide-area network (WWAN) device, which communicates with radio transceivers in a cellular data network while the vehicle is in motion. The network device **152** optionally includes a wireless local area network (WLAN) device for communication with shorter-range wireless local area networks. Examples of WLAN devices include the IEEE 802.11 family of protocols and Bluetooth protocols. In some embodiments, the network device **152** includes a wired network connection, such as Ethernet or USB, for use when the vehicle is parked or for interfacing with another computing device in the compartment of the vehicle. In the system **104**, the processor **108** optionally retrieves polygon data corresponding to one or more of the structure models in the structure model cache **124** from online data services (not shown) using the network device **152**.

In the in-vehicle information system **104**, the global positioning system (GPS) **156** identifies a location of the vehicle for use in navigation applications. In one embodiment, the GPS **156** includes a radio receiver that receives signals from orbiting navigation satellites. Commercially available satellite GPS receivers are integrated in some in-vehicle information systems, and many mobile electronic devices include satellite GPS receivers as well. In an alternative embodiment, the global positioning system **156** receives signals from terrestrial transmitters including WWAN and WLAN transmitters. The global positioning system **156** identifies a location of the vehicle using triangulation or other geolocation techniques. Some embodiments include receivers for both satellite GPS and terrestrial signals. In some embodiments, the global positioning system **156** further includes an inertial navigation system that assists in identifying the location of the vehicle if signals from the satellite or terrestrial transmitters are unavailable. During operation, the processor **108** receives data from the GPS **156** to identify a geographic location of the vehicle. The processor **108** selects a portion of the virtual environment and structures in the virtual environment that correspond to the identified geographic location of the vehicle for display during a navigation operation.

The in-vehicle information system **104** includes one or more display devices **132**. In one embodiment, the display device **132** is a liquid crystal display (LCD), organic light-emitting diode display (OLED) or other suitable display device that generates image output for the vehicle occupants. Displays are commonly mounted in a dashboard or other fixed location in the vehicle. In an alternative embodiment, the display device **132** is a head-up display (HUD) that is projected onto a windshield of a vehicle or projected onto goggles or glasses that are worn by an occupant in the vehicle. In an embodiment where the in-vehicle information system is a handheld mobile electronic device, the display **132** is typically an LCD or organic LED (OLED) flat panel display that is housed in the mobile electronic device.

FIG. **2** depicts a process **200** for classification of structures in a virtual environment and display of the structures using one or more textures that are selected for the structure with reference to the identified classification. FIG. **2** depicts a block diagram of a process **200** for displaying the map features. In the description below, a reference to the process **200** performing or doing some function or action refers to one or more controllers or processors that are configured with programmed instructions, which are executed by the controllers or processors, to implement the process performing the function or action or operating one or more components to perform the function or action. The process **200** is described with reference to the in-vehicle information system **104** of FIG. **1** for illustrative purposes. In the embodiment of the process **200** that is depicted in FIG. **2**, the in-vehicle information **104** classifies a structure as either being a road, regular building, irregular building, or a statue.

Process **200** begins as the processor **108** receives polygon data corresponding to a structure model in a 3D virtual environment (block **204**). In the in-vehicle information system **104**, the cached structure data memory **124** stores polygon data corresponding to one or more structures in the structure model polygon. During operation, the in-vehicle navigation system **104** also retrieves additional structure model polygon data and geolocation coordinates for the corresponding map structures from one or more online data storage services using the network device **152**. As described above, in some instances the online databases include polygon structure model data for the map structures, but do not include classifications for the type of structure. During process **200**, the in-vehicle information system **104** assigns a classification to the retrieved structure model and selects textures for the structure model with reference to the assigned classification to enable generation of map displays with a uniform map layout.

Once the in-vehicle information system **104** receives the polygon data corresponding to a structure, the processor **108** identifies surface normals that correspond to each of the polygons in the structure (block **208**). To generate the surface normal for a polygon, the processor **108** selects the three-dimensional coordinate data for two non-parallel sides of the polygon and performs a cross-multiplication operation on the sides. The cross-multiplication generates a vector that is a surface normal of the polygon. The surface normal vector extends in a perpendicular direction from the face of the polygon. In many 3D graphics system embodiments, the polygons that form the structure models are all triangles, and the processor **108** generates surface normals for the triangles using the three vertex coordinates in the triangle, with one vertex coordinate being used twice to represent an intersection between two sides of the triangle. In the embodiment of FIG. **1**, the memory **120** includes a surface normal storage cache **150**, and the processor **108** stores the generated surface normals in the cache **150**. As described below, the surface normal data are used in different portions of the process **200**, and the surface normal cache **150** enables retrieval of the surface normals without requiring regeneration of the surface normal data. In another embodiment, the processor **108** identifies the surface normals during multiple stages of the process **200**.

During process **200**, if an identified variance of the surface normals for the structure is less than a predetermined variance threshold (block **212**), then the structure is classified as being a road in the 3D virtual environment (block **216**). FIG. **4** depicts a display **400** of a virtual environment that includes roads. In FIG. **4**, a road **404** includes polygons that are formed over a surface of the terrain depicted in the virtual environment display. The surface normals, such as surface normal **408**, for the road **404** have a relatively low variance because the structure model for the road **404** is formed from an approximately planar mesh of polygons that extend across the virtual environment along the path of the road. The surface normals for the road **404** have some variation due to curves and changes in terrain elevation, but the variance for the road surface normals is typically smaller than for normals that correspond to buildings. For example, the buildings **412** and **424** in FIG. **4** include a wider distribution of surface normals, including the normals **416** and **420** for polygons in the building **412**.

FIG. **5** depicts two examples of surface normal distributions, with one distribution **504** corresponding to a road and another distribution **508** corresponding to a structure that is not a road. The graphs **504** and **508** are histograms of the surface normal in two different structure models. Because a surface normal is a vector in a three-dimensional space, the entries along the x-axis in the histograms **504** and **508** correspond to conical regions of a predetermined size that extend from the faces of the polygons in the structure model in the three-dimensional space. For example, referring again to FIG. **4**, the surface normal **408** is contained within a conical region **410** that extends from a polygon in the road structure **404**. In a histogram of surface normals for the road **404**, additional surface normals that are within the conical region **410** are grouped together with the surface normal **408** in the histogram distribution. Other surface normals extend through different conical regions, such as the regions **409** and **411** that are depicted in FIG. **4**. The relatively planar configuration of the polygons that form the road structure **404** results in a large proportion of the surface normal vectors being contained within a relatively small number of conical regions, such as the conical region **410**, in comparison to other structures such as the buildings **412** and **424** in FIG. **4**.

Referring again to FIG. **5**, in the graph **504**, the distribution includes a relatively narrow distribution in an approximately Gaussian shape with a peak **506**. By contrast, the surface normal distribution **508** for non-road structure includes a roughly uniform distribution of surface normals. In the process **200**, the processor **108** identifies the variance of the histogram distribution for the identified surface normals in the structure model, and if the variance for the distribution of surface normals is less than a predetermined variance threshold (block **212**), then the processor **108** identifies that the structure is a road (block **216**).

If the variance of surface normals in the polygon model data exceeds the predetermined threshold (block **212**), then process **200** continues for the classification of other structure types for the structure in the virtual environment. The processor **108** identifies the ratio of the number of polygon faces in the polygon data for the structure model divided by the total number of polygon faces in the structure model (block **220**). The identification of the ratio is described in more detail in FIG. **3**.

FIG. **3** depicts a process **300** for identification of a ratio of polygons in a structure model that are orthogonal to one another divided by the total number of polygons in the model. As used herein, the term “orthogonal” as applied to polygons in a structure model refers to two or more polygons that are oriented in the structure perpendicular to one of three axes that define a three-dimensional coordinate system. Two polygons in a structure can be orthogonal without sharing a common side or vertex in the model. As used herein, orthogonal polygons also include polygons that are parallel to one another. For example, the six sides of a cube are each orthogonal to one another. Many polygon models include rectangular surfaces that are formed from multiple triangles that are arranged in parallel to form the rectangle. The triangles that form the rectangular surface are orthogonal to one another because they can be arranged on a single plane with a single axis in the three-dimensional coordinate system being perpendicular to each of the polygons. In the description below, a reference to the process **300** performing or doing some function or action refers to one or more controllers or processors that are configured with programmed instructions, which are executed by the controllers or processors to implement the process performing the function or action or operating one or more components to perform the function or action. The process **300** is described with reference to the in-vehicle information system **104** of FIG. **1** for illustrative purposes.

The process **300** begins with selection of a single side of a polygon in the polygon data for the structure model and the generation of a first axis in a 3D coordinate space from the selected side (block **304**). FIG. **6** depicts a graphical view of an illustrative structure model **604** that is formed from a plurality of polygons. In FIG. **6**, the polygons in the structure model **604** form a regular building in the virtual environment. In FIG. **6**, solid lines represent the visible edges of the structure **604** as the structure **604** is depicted in a virtual environment, while the dashed lines indicate the interior edges of triangles in the polygon model. Some triangles in the structure model **604** are arranged together to form larger visible polygons such as rectangles in the structure **604**. During process **300**, the processor **108** selects the edges in the polygons that form the structure model **604** and generates a three-dimensional coordinate system from each side in an iterative manner. For example, during one iteration of the processing described with reference to block **304**, the processor **108** selects the edge **608** in the structure model **604**. The processor **108** generates a first axis **628** in parallel with the side **608**. During another iteration of the process **300**, the processor **108** selects the edge **612** and generates the first axis **652** in parallel with the edge **612**.

Process **300** continues as the processor **108** generates a second axis in a 3D coordinate system corresponding to the selected edge of the polygon in the structure (block **308**). The processor **108** identifies the second axis as a surface normal of the polygon that includes the selected edge that forms the basis for the first axis. As described above, the processor **108** generates the surface normal for triangles as a cross-product of two edges in the triangle. During process **300**, the processor **108** generates the normal for the second axis as the cross product of the selected side that forms the first axis and either one of the other two sides of the triangle that includes the selected side. In FIG. **6**, during one iteration of the process **300** the process **108** generates the second axis **632** corresponding to the side **608** and first axis **628**, and in another iteration of the process **300** the processor **108** generates the second axis **650** corresponding to the side **612** and first axis **652**.

Process **300** continues with generation of a third axis for the coordinate system that is generated for the selected edge (block **312**). In one embodiment of the process **300**, the processor **108** performs a cross-multiplication between the first axis and the second axis to generate the third axis. In FIG. **6**, the processor **108** generates the third axis **636** from the cross-product of the axes **628** and **632** in one iteration of the process **300**, and the processor **108** generates the third axis **656** from the cross-product of the axes **652** and **650** in another iteration of the process **300**.

During each iteration of the process **300**, the processor **108** identifies a count of the polygons in the model that are orthogonal to one of the generated three axes (block **316**). At least only one polygon in the model is orthogonal to the axes in each iteration because the axes are generated from one side of one of the polygons in the structure model. In one embodiment, the processor **108** identifies the other orthogonal polygons in the model through generation of surface normals for each of the remaining polygons in the model. If a surface normal for a polygon is parallel to any one of the first, second, and third axes, then the polygon is orthogonal to the original polygon with the side that is used to generate the three axes. In the example of FIG. **6**, the processor **108** generates the surface normals for each of the polygons in the structure model **604** and identifies whether the surface normal is parallel to any one of the three axes. For example, in one iteration of the process **300** the processor identifies that surface normal **672** for the polygon **670** is parallel to the axis **632** during one iteration of the process **300**, and the processor **108** identifies that the surface normal **676** for the polygon **674** is parallel to the axis **652** during another iteration of the process **300**.

In addition to identifying the number of polygons that are orthogonal to the first, second, and third axes in the three-dimensional coordinate system, process **300** also includes identification of a sum of the surface areas for the orthogonal polygons (block **320**). In the in-vehicle information system **104**, the processor **108** identifies the surface area for each orthogonal polygon using geometric techniques that are known to the art. For example, the processor **108** identifies the area of triangles using the formula of A=½b*h where b and h represent the base and height of the triangle. In one embodiment, the processor **108** tessellates more complex polygons into a set of triangles to identify the total surface area of the polygon as a sum of the surface areas of the smaller triangles.

Process **300** continues in an iterative manner for each edge in the polygon data for the structure model (block **324**). During each iteration of process **300**, the processor **108** identifies whether the total surface area of the orthogonal polygons exceeds the maximum identified surface area from any earlier iterations of the process **300**. The processor **108** stores the maximum surface area in association with the count of orthogonal polygons that are identified in association with the maximum surface area. If processor **108** identifies a larger total surface area during another iteration of the process **300**, then the processor **108** updates the maximum surface area and associated orthogonal polygon count. The process **300** continues to process each side of the polygons in the structure model (block **324**), and the processor **108** identifies the ratio of orthogonal polygons to the total number of polygons in the structure model data using the polygon count that is associated with the maximum orthogonal polygon surface area (block **328**).

As described above, the process **300** identifies the number of orthogonal polygons in the polygon data for the structure model. This identification is made using the maximum surface area of orthogonal polygons as a constraint for selecting a polygon for use as the basis for generating the first, second, and third coordinate axes. The maximum surface area constraint is useful in complex structures that include a large number of orthogonal polygons with small surface areas to ensure that a large number of small polygons in the structure do not result in a misclassification of the structure. The ratio that is identified in the process **300** is used in the continued processing of the process **200**.

Referring again to the process **200** in FIG. **2**, if the identified ratio of orthogonal polygon faces to total polygon faces in the polygon data for the structure model exceeds a predetermined threshold (block **224**), then the processor **108** classifies the structure as a regular building (block **228**). The term "regular building" applies to the total proportion of 90° corners that are present in the building model. The orthogonal polygons meet at 90° angles, while non-orthogonal polygons meet at angles other than 90°. Many buildings and other structures in the real world include a high proportion of 90° angle corners, and the corresponding polygon data for the structure models in the virtual environment also include the 90° corners. In one configuration, the ratio threshold is 0.8, which is to say that if 80% or more of the polygons in the structure are orthogonal, then the processor **108** classifies the structure as a regular building.

If the identified ratio of orthogonal polygons to total polygons in the structure model data is below the predetermined threshold (block **224**), then process **200** continues as the processor **108** generates a distribution of dihedral angles in the polygon data of the structure model (block **232**). The dihedral angles refer to angles between adjoining polygons in the structure model. If one of the polygons is rotated through the dihedral angle, then the two polygons are parallel to one another. One method for identifying the dihedral angle between two polygons includes identification of a relationship between surface normals to the two polygons. For example, given polygons A and B with surface normals U_A and U_b, respectively, the dihedral angle between A and B is provided by the following equation, with two equivalent expressions for the dihedral angle:

$$\varphi_{AB} = \arccos\left(\frac{U_A \cdot U_B}{|U_A||U_B|}\right).$$

The processor **108** identifies the dihedral angles between each pair of adjacent polygons in the structure model, and generates a sorted distribution of the angles.

Process **200** continues as the processor then identifies whether the number and magnitude of discontinuities in the distribution of dihedral angles is greater than or less than a predetermined threshold to classify the structure as either an irregular building or a statue (block **236**). In one embodiment, only discontinuities between dihedral angles that are larger than a predetermined angle size are used to classify the irregular buildings and statues. In one embodiment, only discontinuities between dihedral angles that are greater than two radians are used to classify the structure model. In the context of the dihedral angle distributions for structure models, the term "discontinuity" refers to a difference between the sizes of adjacent dihedral angles in the sorted dihedral angle distribution. The maximum difference between two adjacent dihedral angle entries in the sorted dihedral angle data for a given structure model is referred to as the maximum discontinuity for the structure model. Structures that are formed with smooth curves, such as statues, typically have smaller discontinuities between dihedral angles, while irregular buildings tend to have more abrupt changes between dihedral angles.

FIG. **7** depicts two structure models **704** and **724** with respective graphs **708** and **728** of corresponding dihedral angle distributions that the processor **108** generates during the process **200** for the structure models. In FIG. **7**, the structure **704** is an example of an irregular building, which is a stadium as illustrated in FIG. **7**. The irregular building **704** includes a comparatively low number of orthogonal polygons due to the curved outer circumference of the structure. The graph **708** depicts a distribution of the dihedral angles in the structure model **704**, with the y-axis in the graph **708** depicting the dihedral angle in radians, and the x-axis representing an index number assigned to each dihedral angle. The graph **708** increases monotonically to reflect the distribution of dihedral angles in the structure model **704**. In the example of FIG. **7**, the processor **108** identifies discontinuities in dihedral angles that are larger than two radians in size, which are depicted by the portion of the graph **708** that is above the threshold **714**. The distribution depicted in graph **708** includes large discontinuities in the area **720**. In FIG. 7, the structure **724** is a sculpted statue. The dihedral angle distribution graph **728** for the statue **724** includes a comparatively smooth distribution in the region **732** that is above the minimum dihedral angle threshold **714**. In the graph **728**, the changes between adjacent dihedral angles in the distribution for the structure model are smaller than an predetermined threshold, and the graph **728** does not include the large discontinuities **720** that are depicted in the graph **708** for the irregular building **704**.

Referring again to FIG. **2**, if the identified maximum discontinuity between the adjacent dihedral angles of the structure exceed the predetermined threshold (block **236**), then the processor **108** classifies the structure as an irregular building in the virtual environment (block **240**). If, however, the identified discontinuities in the dihedral angles of the structure are less than the predetermined threshold (block **236**), then the processor **108** classifies the structure model as a statue in the virtual environment (block **244**).

As described above in the description of blocks **216**, **228**, **240**, and **244**, the in-vehicle information system **104** classifies the polygon data for the structure model as one of a road, regular building, irregular building, or a statue, respectively. Once the structure is classified, a data identifier for the classification is stored in a memory in association with the structure (block **248**). In the in-vehicle information system **104**, the processor **108** stores classification identification data for the structure in the cached structure classifications region **126** in the memory **120**. The structure classification data are stored in the structure classification cache **126** in association with the cached structure data **124**, and the memory **120** retains the classification for the structure during the display of graphics and other operations in the 3D virtual environment. In one embodiment, the structure classification data are predetermined text strings that conform to a structured data format such as an extensible markup language (XML) format. In another embodiment, the structure classification is a numeric or other binary data identifier.

During process **200**, the in-vehicle information system **104** is configured to display virtual environments including the structures, which are displayed using the polygon data to generate a 3D display of the structure. The in-vehicle information system **104** uses the identified classification for the structure to modify at least one visual aspect of the structure in the 3D virtual environment (block **252**). As used herein, the term "visual aspect" refers to any adjustment to the display of the structure model that is visually perceptible to a typical user of the in-vehicle information system **104**. Examples of visual aspects including, but are not limited to size, shape, color, location, animation, lighting, and textures for the structural model. For example, in one operating mode the classification of an object affects a priority for displaying the object. A road classification is assigned high priority in a navigation application program, while regular buildings are assigned lower priorities. The lower-priority regular buildings are optionally displayed with reduced size, without textures to appear as single-color forms, or are flattened to be shown as 2D graphics instead of full three-dimensional models. In another operating mode, irregular buildings and statues are highlighted with additional lighting to increase the visibility of the structure since irregular buildings and statues are often used as landmarks during navigation.

In another operating mode in the process **200**, the in-vehicle information system **104** selects and applies graphical

textures to the structure models with reference to the classification for each model to modify the visual aspects of a wide range of models to form a more uniform appearance for different structures in the 3D virtual environment. The processor **108** applies a common set of textures to structures in the virtual environment with the same classification to enable generation of a virtual environment with a more uniform appearance. Some existing mapping and navigation applications generate textures for a structure using photographic data to provide a so-called "photorealistic" depiction of the structure in the virtual environment with the same appearance as in the physical world. While photorealistic display of a structure is used in some mapping programs, the photorealistic graphics are often more difficult for a vehicle operator or other vehicle occupant to interpret in a short period of time. In the in-vehicle information system **104**, the processor **108** applies a comparatively limited set of textures to the different structures in the virtual environment with reference to the classification for each structure in order to provide a simplified visual depiction of the 3D virtual environment to the vehicle occupants. The processor **108** selects textures for the structure from the texture memory **134** with reference to the identified classification for the structure In the in-vehicle information system **104**, the processor **108** selects one or more road textures **136**, regular building textures **140**, irregular building textures **144**, and statue textures **148** with reference to the identified classification for the structure.

Process **200** continues as the in-vehicle information system **104** generates a display of the 3D virtual environment including a depiction of the structure model with the modified visual aspect (block **256**). The GPU in **116** in the processor **108** generates a display of the 3D virtual environment including the structure model with the modified visual aspect through the display device **132** for the user to view. In an embodiment where the processor **108** applies textures with reference to the classification for the structure model, the processor **108** applies the textures to the polygons in the structure using, for example, texture-mapping techniques that are known to the art, and generates a display of the 3D virtual environment including the textured structure.

Referring again to FIG. **4**, the display **400** of the virtual environment includes the road **404**, regular buildings such as the regular building **412**, and an irregular building **424**. As depicted in FIG. **4**, the textures that are applied to the road **404** depict a simplified view of a road including lane marks, but are not photorealistic renderings of the road in the physical world that is represented by the road structure model **404** in the display **400**. Similarly, the buildings **412** and **424** have simplified wall and roof textures applied to selected polygons in each structure to generate a graphical depiction of a building, but without rendering photographic details of the building exterior. The processor **108** applies textures to a curved wall **428** in the irregular building **424** to accentuate the curved shape of the irregular building **424** instead of attempting to generate a photographic display of the curved wall **428** in the irregular building **424**. During operation of the in-vehicle information system **104**, the simplified depictions of the structures in the virtual environment enable the vehicle occupants to focus on the task of navigation with fewer distractions because the in-vehicle information system **104** classifies structures in the 3D virtual environment and displays the structures with the predetermined textures.

In one embodiment, the in-vehicle information system **104** in the in-vehicle information system **104** only performs the classification process **200** once for structure models that are previously unclassified. In the embodiment of FIG. **1**, processor **108** stores the classification for each structure in the structure classification cache **126**, which stores the classification in association with the structure model polygon data **124** for each structure that is stored in the memory **120**. During operation of a mapping or navigation application, the processor **108** loads the structure polygon data from the memory **120**, and applies an appropriate set of textures from the textures memory **134** corresponding to roads, regular buildings, irregular buildings, and statues with reference to the previously identified classification for the structure.

It will be appreciated that variants of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems, applications or methods. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements may be subsequently made by those skilled in the art that are also intended to be encompassed by the following claims.

What is claimed is:

1. A method for classification of and display of three-dimensional structures in a virtual environment comprising:

identifying a plurality of polygons in a structure located in a virtual environment;

generating data corresponding to a plurality of surface normals, each surface normal corresponding to one polygon in the plurality of polygons in the structure;

identifying a variance of a distribution of the plurality of surface normals;

generating a first classification for the object in response to the identified variance being below a first predetermined threshold; and

generating with a display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the first classification.

2. The method of claim **1** further comprising:

selecting a first texture from the plurality of textures stored in the memory with reference to the first classification; and

generating with the display device the visual depiction of the structure in the virtual environment with the first texture mapped to the structure.

3. The method of claim **1**, the first classification indicating that the structure is a road in the virtual environment.

4. The method of claim **1**, the identification of the distribution of the plurality of surface normals comprising:

identifying the orientation of each surface normal in the plurality of surface normals;

identifying one conical region in a plurality of conical regions extending from the structure that includes each surface normal in the plurality of surface normals, the identification being made with reference to the identified orientation of each surface normal in the plurality of surface normals; and

generating the distribution as a histogram of a number of the surface normals with orientations corresponding to each conical region in the plurality of conical regions.

5. The method of claim **1** further comprising:

identifying a number of polygons in the structure that are arranged in an orthogonal orientation relative to a plane of a selected polygon in the structure in response to the identified variance being above the first predetermined threshold;

identifying a ratio between the identified number of polygons and a total number of polygons in the structure;

generating a second classification for the structure in response to the identified ratio being above a second predetermined threshold; and

generating with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the second classification.

6. The method of claim **5** further comprising:

selecting a second texture from the plurality of textures stored in the memory with reference to the second classification; and

generating with the display device the visual depiction of the structure in the virtual environment with the second texture mapped to the structure.

7. The method of claim **5** further comprising:

generating three-dimensional axes extending from a plane defined by each polygon in the plurality of polygons in the structure;

identifying a total surface area of the plurality of polygons in the structure that are in an orthogonal orientation to one of the three-dimensional axes for each of the plurality of polygons in the structure; and

identifying the selected polygon as one polygon in the plurality of polygons in the structure with a maximum total surface area for the identified orthogonal polygons.

8. The method of claim **5**, the second classification indicating that the structure is a regular building in the virtual environment.

9. The method of claim **5** further comprising:

identifying a plurality of dihedral angles formed between adjacent polygons in the plurality of polygons in the structure in response to the identified ratio being below the second predetermined threshold;

ordering the plurality of dihedral angles with reference to an identified size for each dihedral angle in the plurality of dihedral angles;

identifying a maximum difference between two consecutive dihedral angles in the ordered plurality of dihedral angles;

generating a third classification for the structure in response to the identified maximum difference being below a third predetermined threshold; and

generating with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the third classification.

10. The method of claim **9** further comprising:

selecting a third texture from the plurality of textures stored in the memory with reference to the third classification; and

generating with the display device the visual depiction of the structure in the virtual environment with the third texture mapped to the structure.

11. The method of claim **9**, the third classification indicating that the structure is a statue in the virtual environment.

12. The method of claim **9** further comprising:

generating a fourth classification for the structure in response to the identified maximum difference being above the third predetermined threshold; and

generating with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the fourth classification.

13. The method of claim **12** further comprising:

selecting a fourth texture from a plurality of textures stored in the memory with reference to the fourth classification; and

generating with the display device a display of the structure in the virtual environment with the fourth texture mapped to the structure.

14. The method of claim **12**, the fourth classification indicating that the structure is an irregular building in the virtual environment.

15. An in-vehicle information system configured to classify and generate a display of structures in a virtual environment comprising:

a memory configured to store:

data corresponding to a plurality of polygons in a structure in a virtual environment; and

data corresponding to a plurality of textures for structures in the virtual environment;

a display device configured to generate a display of the structure in the virtual environment; and

a processor operatively connected to the memory and the display, the processor being configured to:

generate data corresponding to a plurality of surface normals for the data corresponding to the plurality of polygons in the structure, each surface normal corresponding to one polygon in the plurality of polygons in the structure;

identify a variance of a distribution of the plurality of surface normals;

generate a first classification for the object in response to the identified variance being below a first predetermined threshold; and

generate with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the first classification.

16. The system of claim **15**, the processor being further configured to:

select a first texture from the plurality of textures stored in the memory with reference to the first classification; and

generate with the display device the visual depiction of the structure in the virtual environment with the first texture mapped to the structure.

17. The system of claim **16** wherein the first texture depicts a portion of a surface of a road in the virtual environment.

18. The system of claim **15**, the processor being further configured to:

identify the orientation of each surface normal in the plurality of surface normals;

identify one conical region in a plurality of conical regions extending from the structure that includes each surface normal in the plurality of surface normals, the identification being made with reference to the identified orientation of each surface normal in the plurality of surface normals; and

generate the distribution as a histogram of a number of the surface normals with orientations corresponding to each conical region in the plurality of conical regions.

19. The system of claim **15**, the processor being further configured to:

identify a number of polygons in the structure that are arranged in an orthogonal orientation relative to a plane of a selected polygon in the structure in response to the identified variance being above the first predetermined threshold;

identify a ratio between the identified number of polygons and a total number of polygons in the structure;

generate a second classification for the structure in response to the identified ratio being above a second predetermined threshold; and

generate with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the second classification.

20. The system of claim **19**, the processor being further configured to:

select a second texture from the plurality of textures stored in the memory with reference to the second classification; and

generate with the display device the visual depiction of the structure in the virtual environment with the second texture mapped to the structure.

21. The system of claim **19**, the processor being further configured to:

generate three-dimensional axes extending from a plane defined by each polygon in the plurality of polygons in the structure;

identify a total surface area of the plurality of polygons in the structure that are in an orthogonal orientation to one of the three-dimensional axes for each of the plurality of polygons in the structure; and

identify the selected polygon as one polygon in the plurality of polygons in the structure with a maximum total surface area for the orthogonal polygons.

22. The system of claim **20** wherein the second texture depicts a portion of a surface of a regular building in the virtual environment.

23. The system of claim **19**, the processor being further configured to:

identify a plurality of dihedral angles formed between adjacent polygons in the plurality of polygons in the structure in response to the identified ratio being below the second predetermined threshold;

order the plurality of dihedral angles with reference to an identified size for each dihedral angle in the plurality of dihedral angles;

identify a maximum difference between two consecutive dihedral angles in the ordered plurality of dihedral angles;

generate a third classification for the structure in response to the identified maximum difference being below a third predetermined threshold; and

generate with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the third classification.

24. The system of claim **23**, the processor being further configured to:

select a third texture from the plurality of textures stored in the memory with reference to the third classification; and

generate with the display device the visual depiction of the structure in the virtual environment with the third texture mapped to the structure.

25. The system of claim **24** wherein the third texture depicts a portion of a surface of a statue in the virtual environment.

26. The system of claim **23**, the processor being further configured to:

generate a fourth classification for the structure in response to the identified maximum difference being above the third predetermined threshold; and

generate with the display device a visual depiction of the structure in the virtual environment with at least one visual aspect of the structure being modified with reference to the fourth classification.

27. The system of claim **26**, the processor being further configured to:

select a fourth texture from a plurality of textures stored in the memory with reference to the fourth classification; and generate, with the display device, a display of the structure in the virtual environment with the fourth texture mapped to the structure.

28. The system of claim **27** wherein the fourth texture depicts a portion of a surface of an irregular building in the virtual environment.

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